AL-TP-1992-0057

AD-A258 621

ARMSTRONG LABORATORY

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MULTIPLE PROJECTOR SMALL DOME DISPLAY

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December 1992

Final Technical Paper for Period June 1991 - July 1992

AIR FORCE MATERIEL COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
December 1992

3. REPORT TYPE AND DATES COVERED
Final – June 1991 – July 1992

4. TITLE AND SUBTITLE
Multiple Projector Small Dome Display

5. FUNDING NUMBERS
C – F33615-88-C-0001
PE – 62205F
PR – 1123
TA – 04
WU – 01

6. AUTHOR(S)
Diane A. Hughes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
GE Government Services, Incorporated
General Electric Company
P.O. Box 137
Gilbert, AZ 85234

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Division
Williams Air Force Base, AZ 85240-6457

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL-TP-1992-0057

11. SUPPLEMENTARY NOTES

Armstrong Laboratory Technical Monitor: Dr. Byron J. Pierce, (602) 988-6561

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This document describes the Multiple Projector Small Dome Display Project. The goal of this project was to demonstrate the capability of current low-cost liquid crystal display projectors to create a low-cost dome display system. Four such projectors were configured to project on a 10-ft-diameter half-dome. The ability of the image generator to precorrect the image for the distortion of the curved projection surface was essential since the projectors offered no raster adjustments. As configured for this project, the four projectors provided a field of view of 70 degrees horizontal by 45 degrees vertical. Performance of the display provided better than 6 arc minutes per pixel resolution, brightness of 4 foot-lamberts and a contrast ratio of 28 to 1.

14. SUBJECT TERMS

Aspect ratio	Distortion correction	Low cost dome display
Brightness blending	Field of view	Viewer attitude
Design eyepoint	Liquid crystal display projectors	Window definitions

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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PREFACE

The object of the Multiple Projector Small Dome Display (MPSDD) project was to design, build, and demonstrate a display system using liquid crystal display (LCD) projector technology in a low-cost dome display system.

This research represents a portion of Armstrong Laboratory, Aircrew Research Training Division, research and development in support of the Aircrew Training Technology Development program whose goals include the design, development, and evaluation of new methods, equipment, and simulator devices for use in aircrew training.

This research was conducted under Work Unit 1123-04-01, Technical Support for Visual and Sensor Scene Generators and display Operations and Maintenance. Work was accomplished under Contract No. F33615-88-C-0001 with GE Government Services, Incorporated. The Technical Contract Monitor was Mr. Daniel H. Mudd.

MULTIPLE PROJECTOR SMALL DOME DISPLAY

INTRODUCTION

This document describes the Multiple Projector Small Dome Display (MPSDD) project. The object of the MPSDD project was to design and build a low-cost dome display using four liquid crystal display (LCD) projectors and an existing 10 ft. diameter half dome. The on-site Advanced Visual Technology System (AVTS) image generator (IG) produced the visual scene.

BACKGROUND

Four color Sharp XV100 LCD projectors were configured to front-project the visual scene on the dome. The LCD projectors provided a visual which meets specifications of the National Television Standard Committee (NTSC) 525-line rate. AVTS was modified to provide Electronic Industries Association (EIA) RS170A, 525-line, RGBS (red, green, blue, and sync) video.

An existing 10 ft. diameter unity gain half dome was moved into A-Bay of Building 558, at Williams Air Force Base, Arizona.

The on-site AVTS image generator was used to provide the four channels of imagery required. The AVTS distortion correction maps and window definitions software were modified to produce a scene on the small radius dome. Brightness blending was accomplished by varying intensities of the overlapping region.

DISPLAYS

Display Setup

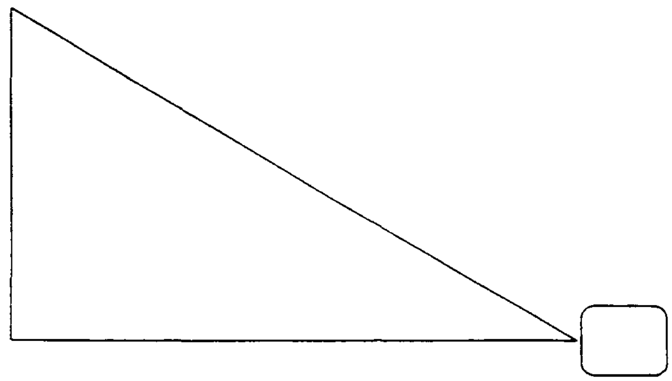
The LCD projectors were placed 15 ft. behind the dome center to ensure enough room for installation of a cockpit. Projectors were located 18 in. left or right of the stand center for symmetry. The projectors were set up on a secure metal stand to keep them stationary. Two of the projector lens locations were 68 in. above the floor. The other two were directly above them at 86 in. above the floor. These locations were chosen to maximize coverage of the dome while avoiding obstruction of the visual scene by the viewer's head. The projectors were angled to compensate for the optical axis of the LCD projection not being symmetrical

in the vertical direction, as shown in Figure 1. The layout of the MPSDD is shown in Figures 2 and 3.

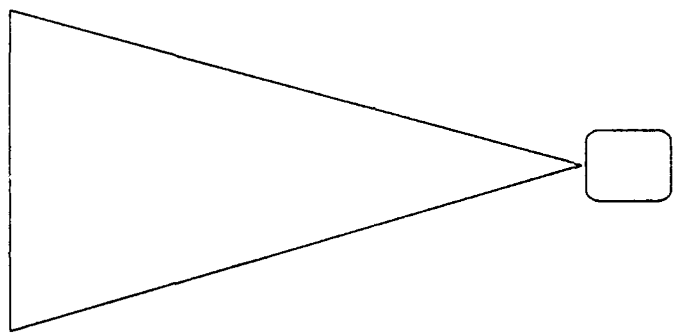
A laser theodolite was set up to take precise azimuth and elevation measurements of the projected rasters, after the half dome and the projectors were initially positioned. The windows defining the video scene were distorted due to the curvature of the half dome. Azimuth and elevation readings were taken to calculate the angles needed for field of view (FOV), aspect ratio, viewer attitude, and projector window definitions.

Field of View

The viewer FOV is the vertical and horizontal field of view of the display as measured from the Design Eyepoint (DEP). The DEP is the designated x, y, and z position, referenced with respect to the dome center from which the viewer looks at the display. The design goal was a FOV from the DEP that measured 100 degrees horizontal by 80 degrees vertical. The actual FOV obtained was 70 degrees horizontal and 45 degrees vertical. This decreased FOV was due to brightness blending and overlap requirements to accommodate distortion correction. This issue will be discussed later in the paper. The FOV is also dependent on DEP, which was moved back due to cockpit constraints, creating a smaller FOV, but higher viewer resolution.



LCD Projector - Side View



Standard Projector - Side View

Figure 1. Optical Axis of the LCD and a Standard Projector

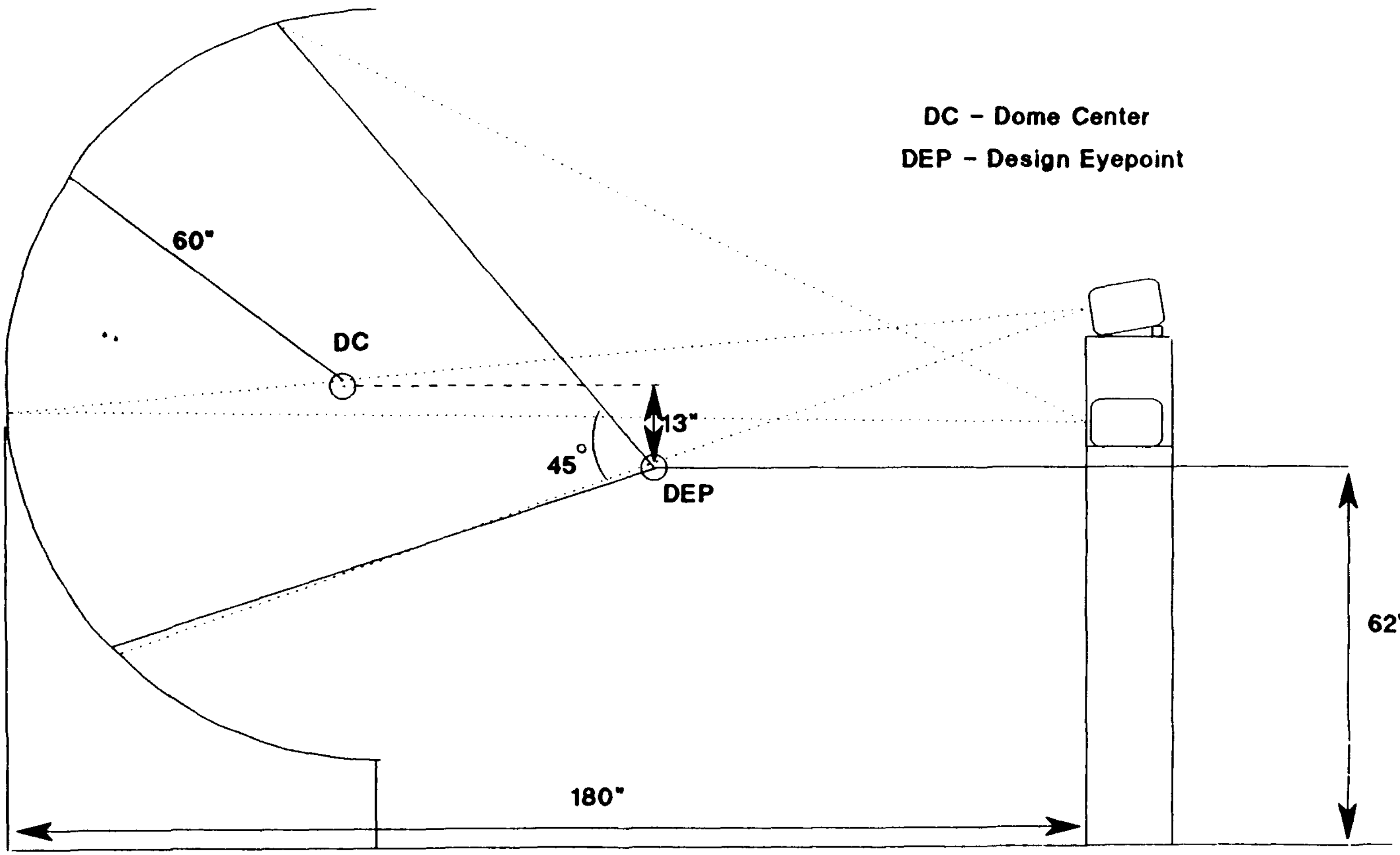


Figure 2. MPSDD - Side View

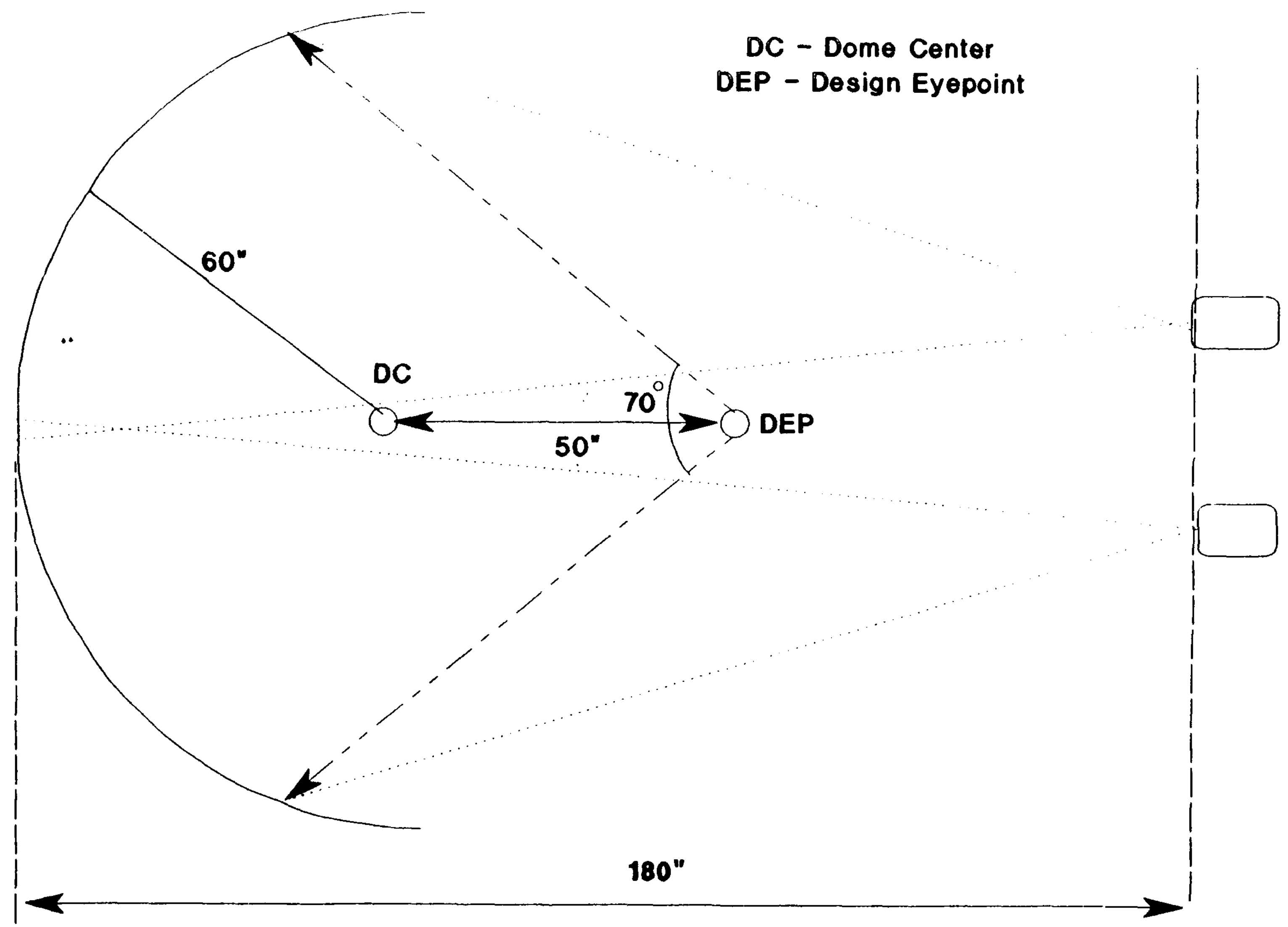


Figure 3. MPSDD - Top View

The FOV for the projector is the vertical and horizontal angle subtended by the light exiting the projection lens. The FOV measurements for the projector were taken to determine the proper distortion correction and window definitions. The projector FOV was calculated by measuring the azimuth and elevation positions of the video edges with respect to the dome center and converting the values to relate to DEP coordinates using the following equations:

$$z = R \sin(el)$$

$$y = R \cos(el) \sin(az)$$

$$x = R \cos(el) \cos(az)$$

el: elevation

az: azimuth

R: radius of dome

x: where the measured az and el pixel location is on the x axis

y: where the measured az and el pixel location is on the y axis

z: where the measured az and el pixel location is on the z axis

The FOV for the horizontal and vertical axes were calculated after the azimuth and elevation measurements were converted to x, y, and z form. The x, y, and z coordinates are recorded in appendix A for each LCD projector. An example of the horizontal FOV is diagramed in Figure 4. The vertical FOV is not shown but is similar to the horizontal FOV. The average horizontal FOV (angle C - as shown in Figure 4) is 21.78 degrees and the vertical is 15.44 degrees. The horizontal and vertical FOV angles for each of the LCD projectors are in appendix B.

$$a = ((X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2)^{1/2}$$

$$b = ((X_1 - X_3)^2 + (Y_1 - Y_3)^2 + (Z_1 - Z_3)^2)^{1/2}$$

$$c = ((X_3 - X_2)^2 + (Y_3 - Y_2)^2 + (Z_3 - Z_2)^2)^{1/2}$$

$$C = \cos^{-1}\left[\frac{a^2 + b^2 - c^2}{2ab}\right]$$

X_1, Y_1, Z_1: the coordinates of the projector location

X_2, Y_2, Z_2: the coordinates of the outside edge of the window

X_3, Y_3, Z_3: the coordinates of the inside edge of the window

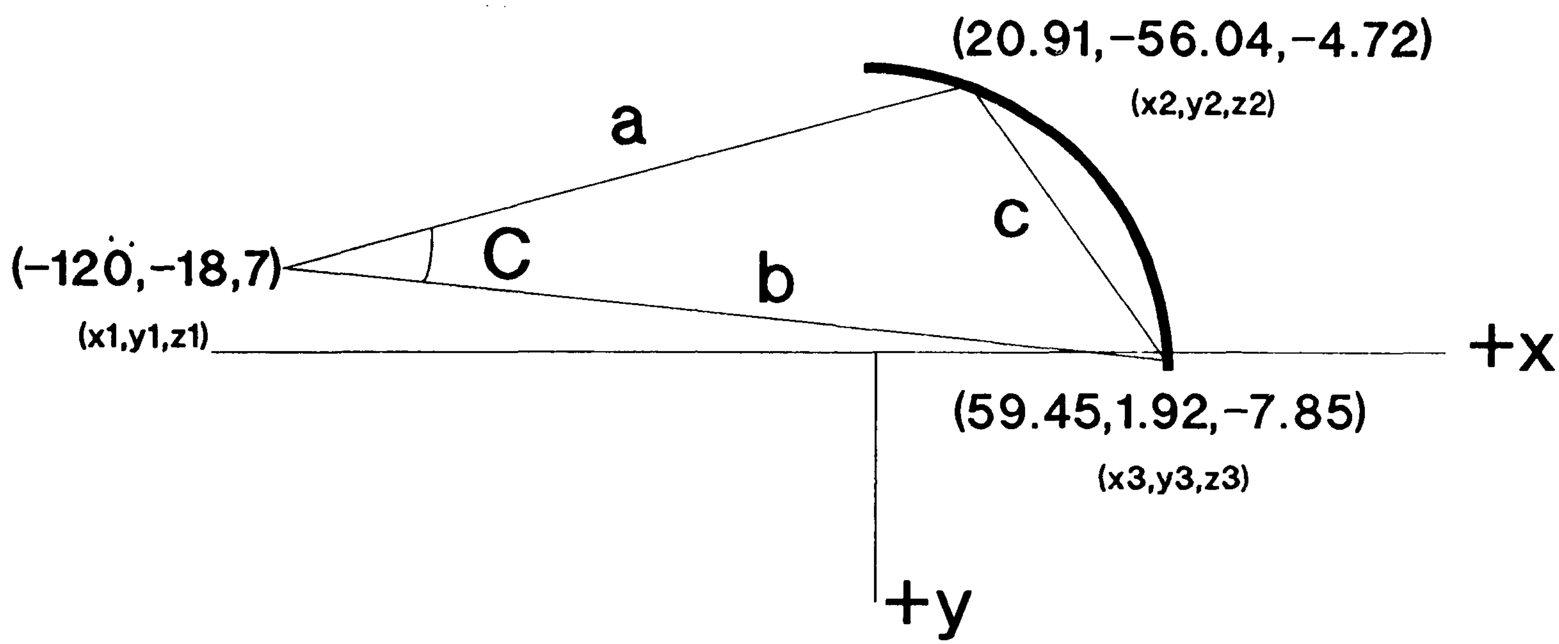


Figure 4. Horizontal FOV – Top View

a: the adjacent side

b: the hypotenuse side

c: the opposite side

C: the angle in degrees of the FOV

Aspect Ratio

Next, the Aspect Ratio was calculated. The Aspect Ratio is the ratio of vertical FOV to horizontal FOV.

$$\frac{\text{Vertical FOV}}{\text{Horizontal FOV}} = \text{Aspect Ratio}$$

The average Aspect Ratio for the four projectors was .73, close to a 3:4 ratio.

Viewer Attitude

The Viewer Attitude is the vector from the eyepoint to the center pixel of each displayed raster. Determining the Viewer Attitude was necessary to determine the proper distortion correction. This was calculated by converting the azimuth and elevation readings of the center pixel positions to x, y, and z coordinates, and then subtracting the distance from dome center to the eyepoint location. After this was done, the x, y, and z coordinates had to be converted back to azimuth and elevation values to allow proper computation of distortion correction.

$$el = \tan^{-1}\left[\frac{z}{(x^2 + y^2)^{1/2}}\right]$$

$$az = \tan^{-1}\left[\frac{y}{x}\right]$$

DISTORTION CORRECTION AND WINDOW DEFINITIONS

The work on distortion correction maps and window definitions was initiated once the measurements and calculations were completed. Two problems had to be solved in this area. The first was how to generate distortion correction video that was 478 lines by 848 elements, instead of the AVTS standard 985 lines by 1000 elements. The visible lines and elements displayed were measured with the use of the AVTS Test and Diagnostic Language (TDL) cursor program, which has the capability to display an "X" at any pixel location in the video. This program was utilized to locate the pixel position of each of the four rasters on the dome surface.

The second problem was due to a unique characteristic of the LCD projector. The projector is designed so the bottom edge of its projected raster is level with the height of the output lens. As shown in Figure 1, the axis of symmetry is

located at the center of the bottom of the projected window, with no available adjustments. Calculations were derived to compensate for the off-axis conditions in the LCD projectors to provide correct window definitions.

$$R_{left} = \tan^{-1}(HSC * \tan(HFOV/2))$$

$$R_{right} = \tan^{-1}\left(\left[\frac{K_E - LinNum}{LinNum}\right] * \tan R_{Left}\right)$$

$$R_{top} = \tan^{-1}(VSC * \tan(HFOV/2))$$

$$R_{bottom} = \tan^{-1}\left(\left[\frac{K_L - EleNum}{EleNum}\right] * \tan R_{top}\right)$$

HSC: the horizontal scaling coefficient

VSC: the vertical scaling coefficient

HFOV: the horizontal lens field of view

LinNum: the number of lines (vertical) displayed by the LCD (478)

EleNum: the number of elements (horizontal) displayed by the LCD (848)

K_L: the number of lines (vertical) in the view window (700)

K_E: the number of elements (horizontal) in the view window (1000)

R_{left}, R_{right}, R_{top}, R_{bottom} are the angles from the center pixel to the appropriate edge of the window. The actual size of the displayed video is 2 times R_{left} by 2 times R_{top}. The extra lines and elements in R_{bottom} and R_{right} are needed only in view space (window definitions) to fill the projector window after distortion correction is applied.

The first set of vertical and horizontal scaling coefficients were estimated for determining distortion correction maps. The resulting maps were checked to determine whether the IG could accept the values. On the AVTS, all view space pixels must map within the 1024 x 1024 pixel Video Memory Combiner (VMC). The numbers were adjusted and the process repeated until the conditions were satisfied. When the values were accepted, the window definitions were generated. The distortion correction maps and window definitions were checked by "flying" the AVTS visual system to verify if any overloading occurred. An IG overload occurs when processing capabilities are exceeded causing portions of the projected video scene to not be properly displayed. Theodolite measurements were taken to quantify scaling and offset errors. The window definitions and distortion correction parameters were adjusted until the four window edges lined up properly, with objects transferring smoothly from window to window, producing a

matchup of the visual scene as shown in Figure 5. The trees show an example of why the window definitions need to be extremely accurate. When an object is within more than one window, the object's contours will not be lined up if the match is less than ideal.

It was discovered that distortion correction processing did not fill the entire LCD-projected raster with video when 478 lines and 848 elements were used in the window definition. The lines and elements used in the window definition were increased to 700 and 1000. This enabled the proper size raster to be projected on the screen while accounting for distortion correction.

AVTS VISUAL SYSTEM

The AVTS window generation software was modified to define the statically distorted windows and to be capable of initializing the software load. The Frame I real-time program was modified so special landing lights could be loaded for brightness blending from the Global Memory Initializer program. The Shared Memory File was altered to automatically bring up the four windows, landing lights, and 525-line rate. The IG TDL hardware initialization program was also modified to bring up distortion correction maps.

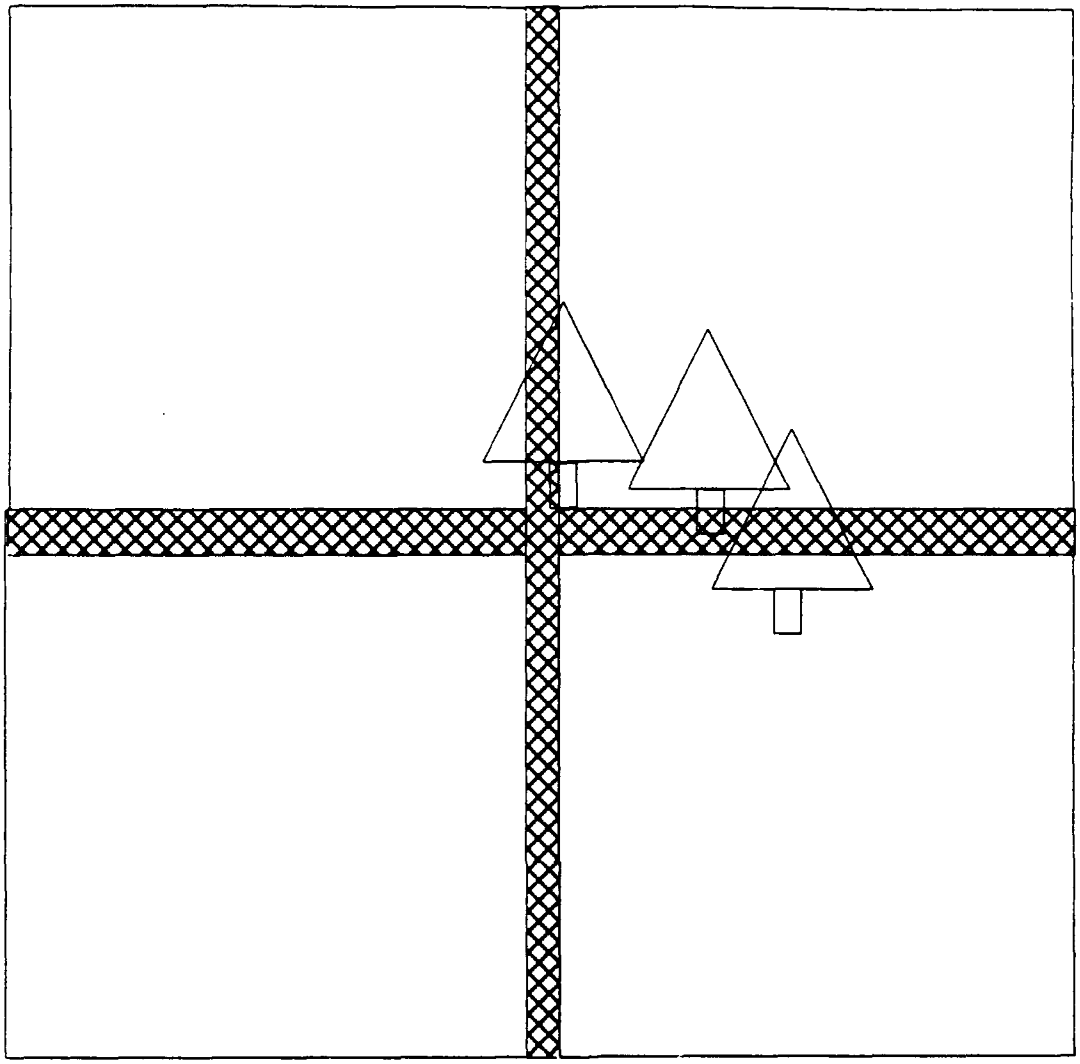


Figure 5. Overlapped Blended Region of the Projected Four Windows

OVERLAPPED

BLENDED REGION

The LCD projectors require NTSC video which uses a 525-line rate. The IG was modified to output RS 170A line rate. Commercially available synchronization conversion units were acquired to convert the separate RGBS (red, green, blue and sync) outputs from AVTS to NTSC composite video. Figure 6 shows the configuration of these conversion units.

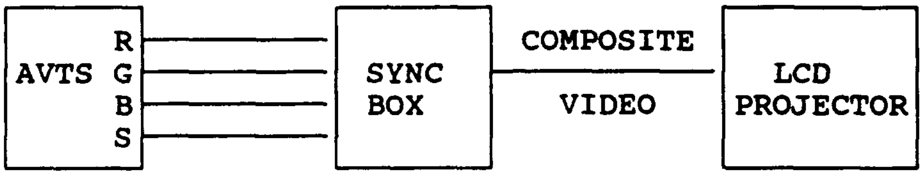


Figure 6. Conversion from RGBS to NTSC Composite Video

BRIGHTNESS BLENDING

The brightness blending work was initiated after the distortion correction maps and window definitions were completed. The adjacent edges of the four windows had to be blended in order to eliminate the bright boundary lines between the windows. A static blending mask was loaded to provide varying intensities for each overlapping subspan by using the Landing Light Coefficient (LLC). The value was multiplied, along with the fading, haze, modulation, and color values, to obtain the final color values output by the IG. The LLC value can range from 0 to FFFF hex.

The AVTS TDL cursor program was used to change the LLC values. Each window was worked on separately. Each

eight-by-eight pixel subspan was changed, one at a time, until the desired illumination of that span was achieved. This process was repeated until the overlapping edges of all windows were blended properly.

Insufficient overlap of the windows was apparent after the blending work began. The overlap was expanded by increasing the scaling coefficients for each window to the maximum values without causing overloading in the IG hardware.

There were several design challenges associated with the task of brightness blending. Moving the projectors to generate more overlap required changing the distortion maps and the blending maps for a proper match.

Another challenge was compensating for the steep curvature of the dome surface. The radius of the dome used for this project was 5 ft. and the projectors 15 ft. from the surface. This caused the outer edges of the projected rasters to fall on steeply curved areas of the dome surface. This meant that the subspans from each window were not aligned between overlapping windows causing light or dark areas in those regions. Eight pixel spans did not provide sufficiently fine control to completely eliminate these brightness variations.

CONCLUSION

The MPSDD achieved its goal of demonstrating the present LCD projector technology in a low-cost display system. The calculated average resolution for the vertical window was 5.95 arcminutes/pixel and the horizontal window was 5.47 arcminutes/pixel. An average maximum white brightness of 4.02 foot-lamberts was measured with a contrast ratio of 28:1. The projected brightness of each window decreased an average of 55 percent toward the edges. The displayed window edges did not blend completely using 8-pixel spans for compensation. For a small radius dome, pixel by pixel adjustment would probably be required to eliminate the distinct areas of brightness variation caused by overlapping video. The overall FOV of the final display configuration was 70 degrees horizontal by 45 degrees vertical.

Some advantages of the LCD projector are low cost and a lightweight package. The single output lens of the LCD projector provides convergence-free projection for easy setup. The zoom lens feature provides latitude in positioning the projector with respect to the screen. Reliability of the LCD projectors thus far has been excellent with no problems since installation.

Some disadvantages of the LCD projectors are reduction in picture quality as individual LCD elements fail, a lack of geometry adjustment, and restriction to the low resolution, 525-line format.

APPENDIX A
THE FOV X, Y, AND Z COORDINATES

PROJ	HORIZONTAL FOV X1,Y1,Z1	: X2,Y2,Z2	: X3,Y3,Z3
1	-120,-18,7	20.9,-56.0,-4.7	59.5,1.9,-7.9
2	-120,18,7	59.5,-1.6,-7.8	20.4,56.2,-5.0
3	-120,-18,-11	0.1,-53.5,27.2	46.7,1.8,37.7
4	-120,18,-11	46.7,-1.3,37.7	6.5,53.4,26.6

PROJ	VERTICAL FOV X1,Y1,Z1	: X2,Y2,Z2	: X3,Y3,Z3
1	-120,-18,7	33.5,0.3,-49.8	59.5,1.9,-7.8
2	-120,18,7	33.5,-0.3,-49.8	59.5,-1.6,-7.8
3	-120,-18,-11	59.4,1.4,-8.6	46.7,1.8,37.7
4	-120,18,-11	59.4,-1.2,-8.6	46.7,-1.3,37.7

X_1, Y_1, Z_1: the coordinates of the projector location in inches

X_2, Y_2, Z_2: the coordinates of the outside edge of the window in inches

X_3, Y_3, Z_3: the coordinates of the inside edge of the window

APPENDIX B
THE FOV ANGLE

PROJ	HORIZONTAL FOV a	b	c	C
1	146.42	181.17	70.74	21.81
2	146.00	181.14	69.85	21.39
3	130.89	174.75	73.08	22.29
4	136.65	174.71	67.73	20.89

PROJ	VERTICAL FOV a	b	c	C
1	164.69	181.17	49.32	15.47
2	164.69	181.14	49.36	15.48
3	174.75	180.43	47.95	15.41
4	174.71	180.42	47.94	15.41

a: the adjacent side in inches
b: the hypotenuse side in inches
c: the opposite side in inches
C: the angle in degrees of the FOV

ACRONYMS

1.	AVTS	Advanced Visual Technology System
2.	DEP	Design Eyepoint
3.	EIA	Electronic Industries Association
4.	FOV	Field Of View
5.	IG	Image Generator
6.	LCD	Liquid Crystal Display
7.	LLC	Landing Light Coefficient
8.	MPSDD	Multiple Projector Small Dome Display
9.	NTSC	National Television Standard Committee
10.	RGBS	Red, Green, Blue, and S[illegible]
11.	TDL	Test and Diagnostic Language
12.	VMC	Video Memory Combiner